

# METHODS OF TAILORING MAGNETIC PROPERTIES OF MAGNETIC COMPOSITES

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## Introduction

Magnetic elements are manufactured by different methods, such as casting, sintering, compression moulding or injection moulding. The last two methods are the ways for production magnetic composites. One of the main advantages of magnetic composites is possibility of tailoring their physical properties. The technology of production enables to prepare elements of net shape and size, with high accuracy, without additional machining.

## Experiments and results

Soft and hard magnetic composites are prepared from magnetic materials in the form of powder. Injection and compression moulding methods can be used for preparing soft and hard magnetic elements of magnetic circuits. Hard magnetic elements prepared by injection or compression moulding are called bonded magnets or dielectromagnets [1,2]. Soft magnetic elements are called SMC (soft magnetic composites) or dielectromagnetics [5]. These composite materials are widely developed [4,6,7].

The methods of tailoring physical properties of magnetic composites are: selection of technology, selection of kind and amount of magnetic powder, selection of kind and amount of binding agent, selection of kind and amount of admixing powders, selection of parameters of the technology used, i.e., pressure, temperature and time of curing for compression moulding, pressure and temperature of injection moulding.

### 1. Permanent magnets

As hard magnetic materials ferrite powder, samarium-cobalt powder can be used. But the broadest development is observed in Nd-Fe-B powders. The powder for bonded magnets is mainly prepared by melt-spinning; in consequence ribbons with grain size about 70 nm are obtained. The average grain size of powder from melt-spun ribbon is about 200  $\mu\text{m}$ . Epoxy resin was used as a binder for compression moulding, and polystyrene for injection moulding.

For permanent magnets the most important parameters are maximum density of magnetic energy  $(\text{BH})_{\text{max}}$ , magnetic remanence  $B_r$ , coercivity of magnetic flux density  $H_{\text{cB}}$ , and coercivity of magnetic polarization  $H_{\text{cJ}}$ .

The technology applied has influence on magnetic properties of hard magnetic composite as shown in table 1. The results of measurements of samples' magnetic properties show, that samples prepared by injection moulding have lower magnetic properties. It is connected with lower amount of magnetic powder in the mixture of powder and binding agent. In the mixture of powder and

resin for compression moulding technology there is about 97.5 wt. % of magnetic powder while in mixture of powder and binding substance for injection moulding is about 87.5 wt. % of magnetic powder.

Table 1 Magnetic properties of Nd-Fe-B bonded permanent magnets [1].

Kind of moulding	$B_r$ (T)	$H_{\text{cJ}}$ (kA/m)	$H_{\text{cB}}$ (kA/m)	$(\text{BH})_{\text{max}}$ (kJ/m <sup>3</sup> )
Injection	0.47	829	328	40.7
Compression	0.71	735	454	82.7

Another method of tailoring physical properties of composites is selection of amount of resin. Table 2 shows the influence of the proportion of resin on magnetic properties of bonded magnets.

Table 2 Magnetic properties of compression moulding Nd-Fe-B bonded magnets [2].

Amount of resin	$B_r$ (T)	$H_{\text{cJ}}$ (kA/m)	$H_{\text{cB}}$ (kA/m)	$(\text{BH})_{\text{max}}$ (kJ/m <sup>3</sup> )
2% wt.	0.63	920	456	74.4
4% wt.	0.58	920	432	62.7

With increasing amount of resin in the mixture magnetic properties have decreased. It is connected with decreasing the amount of hard magnetic powder in the samples.

In order to compare the influence of the kind of powders on composites' magnetic properties barium ferrite and Nd-Fe-B magnets were prepared by injection moulding. Table 3 shows results of measurements of magnets. The powder of barium ferrite has lower magnetic properties than Nd-Fe-B powder and hence magnetic properties of barium ferrite composites are lower than magnetic properties of Nd-Fe-B composites.

Table 3 Magnetic properties of injection moulding magnets [2].

Composition of magnets	$B_r$ (T)	$H_{\text{cJ}}$ (kA/m)	$H_{\text{cB}}$ (kA/m)	$(\text{BH})_{\text{max}}$ (kJ/m <sup>3</sup> )
Nd-Fe-B	0.37	1216	296	38.7
Barium Ferrite	0.13	98	77	3.0

Another method of tailoring properties of hard magnetic composites is admixture to the basic powder of another type of metal powder [3]. Properties of composite depend on the kind and amount of powder admixed. In our experiments soft magnetic iron powder and paramagnetic aluminum powder were used. Results of measurements are presented in table 4.

Table 4 Magnetic properties of compression moulding Nd-Fe-B bonded magnets with different admixing powders [3].

Composition of magnets	$B_r$ (T)	$H_{cJ}$ (kA/m)	$H_{cB}$ (kA/m)	$(BH)_{max}$ (kJ/m <sup>3</sup> )
Nd-Fe-B 100 %	0.72	730	460	80
Nd-Fe-B 70 wt. % +Al 30 wt. %	0.38	777	270	27
Nd-Fe-B 70 wt. % +Fe 30 wt. %	0.74	454	252	46

In the case of soft magnetic powder we can observe significant decrease of coercivities and little increase of remanence. In the case of aluminum powder being used all magnetic parameters decrease parallelly besides  $H_{cJ}$ . Important factor influencing the sample's parameter is parameter of production technology such as compacting pressure. The optimum pressure is among 700-900MPa for compression moulding technology. Less important for magnetic parameters of magnets are temperature and time of curing, dependent on type of resin.

## 2. Soft magnetic composites

The same methods of tailoring physical properties can be applied for compression moulding soft magnetic composites as those applied for hard magnetic composites. In our experiments high pure iron, cobalt and nickel powders were used as soft magnetic powders and were bound with epoxy resin.

Table 5 shows magnetic properties of soft magnetic composites prepared from Fe, Co and Ni powders. The best magnetic properties are to be found in samples prepared from iron powder. Maximum magnetic permeability is 239 and magnetic flux density 1.05T and 1.35T at applied magnetic field intensity 5000A/m and 10000A/m respectively. Measuring frequency was 50Hz.

Table 5 Magnetic properties of soft magnetic composites.

Kind of soft magnetic powder	$\mu_{r \max}$ (-)	$B_{5000A/m}$ (T)	$B_{10000A/m}$ (T)
Fe	239	1,05	1,35
Co	9	0,05	0,11
Ni	15	0,07	0,17

In order to show the influence of technological parameters on soft magnetic composites, i.e., pressure, temperature and time of curing, the samples from iron powder were processed. In table 6 magnetic properties of samples prepared with different technological parameters are presented.

Table 6 Magnetic properties of Somaloy™ 500 iron soft magnetic composites.

Technological parameters of production	$\mu_{r \max}$ (-)	$B_{5000A/m}$ (T)	$B_{10000A/m}$ (T)
400 MPa/500°C/0.5h	293	0.95	1.15
800 MPa/500°C/0.5h	405	1.25	1.48
800 MPa/350°C/0.5h	333	1.20	1.46

In the case of soft magnetic composites pressure and temperature are decisive for magnetic properties.

There are different types of iron powders available on the market. Different powders allow to prepare magnetic composites with different magnetic properties - table 7.

Table 7 Magnetic properties of iron soft magnetic composites.

Kind of commercial powder	$\mu_{r \max}$ (-)	$B_{5000A/m}$ (T)	$B_{10000A/m}$ (T)
Somaloy™ 500	405	1.25	1.48
Atomet™ EM-2	300	1.10	1.37

## Conclusion

The results of experiments have shown that there is a possibility of tailoring magnetic properties of composites.

## References

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